4.0 Technical Approach

Establishing the relationship between the in-stream water quality targets and source loadings is a critical component of TMDL development. It allows for evaluation of management options that will achieve the desired source load reductions. The link can be established through a range of techniques, from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions. The objective of this section is to present the approach taken to develop the linkage between sources and in-stream response for TMDL development in the Guyandotte watershed.

4.1 Model Framework Selection

Selection of the appropriate approach or modeling technique requires consideration of the following:

- Expression of water quality criteria
- Dominant processes
- Scale of analysis

Numeric aquatic life water quality criteria for aluminum, iron, and selenium, such as those applicable here, require evaluation of magnitude, frequency, and duration. Magnitude refers to the value of the criterion maximum concentration (CMC) to protect against short-term (acute) effects, or the value of the criterion continuous concentration (CCC) to protect against long-term (chronic) effects. Frequency indicates the number of water quality criteria exccedances allowed over a specified time period. West Virginia Water Quality Standards allow one accedence of aquatic life criteria every three years on average. Duration measures the time period of exposure to instream pollutant concentrations. For CMC criteria, exposure is measured over a one-hour period, while exposure for CCC criteria is measured over a four-day period. In addition to these considerations, any technical approach must consider the form of expression of numeric aquatic life criteria that are expressed. West Virginia aquatic life criteria for iron and selenium are expressed in the total recoverable metal form and the criteria for aluminum are expressed as concentrations in the dissolved metal form.

Total fecal coliform bacteria and total manganese criteria are prescribed for the protection of the human health uses of water contact recreation and public water supply. They are presented as a geometric mean concentration, using a minimum of five consecutive samples over a 30-day period, and a maximum daily concentration that is not to be exceeded in more than 10 percent of all samples taken in a month. No accedence of human health protection criteria is allowed.

West Virginia water quality criteria are applicable at all stream flows greater than the 7Q10 flow. The approach or modeling technique must permit representation of in-stream concentrations under a variety of flow conditions in order to evaluate critical flow periods for comparison to chronic and acute criteria.

According to 40 CFR Section 130, TMDLs must be designed to implement applicable water quality standards. The applicable water quality standards for metals, pH and fecal coliforms in West Virginia are presented in Section 2, Table 2-1.

The TMDL development approach must also consider the dominant processes regarding pollutant loadings and in-stream fate. For the Guyandotte watershed, primary sources contributing to metals, pH, and fecal coliform impairments include an array of point and nonpoint sources. Loading processes for nonpoint sources or land-based activities are typically rainfall-driven and thus relate to surface runoff and subsurface discharge to a stream. Permitted discharges may or may not be induced by rainfall.

Key in-stream factors that could be considered include routing of flow, dilution, transport of total metals, sediment adsorption/desorption, and precipitation of metals. In the stream systems of the Guyandotte watershed, the primary physical driving process is the transport of total metals by diffusion and advection in the flow. A significant in-stream process affecting the transport of fecal coliform bacteria is fecal coliform die-off.

Scale of analysis and waterbody type must also be considered in the selection of the overall approach. The approach should have the capability to evaluate watersheds at various scales. The listed waters in the Guyandotte watershed range from small headwater streams to larger tributaries and the Guyandotte River mainstem. Selection of scale should be sensitive to locations of key features, such as abandoned mines and point source discharges. At the larger watershed scale, land areas are lumped into subwatersheds for practical representation of the system, commensurate with the available data. Occasionally, there are site specific and localized acute problems which may require more detailed segmentation or definition of detailed modeling grids.

Based on the considerations described above, analysis of the monitoring data, review of the literature, and past pH, metals, and fecal coliform bacteria modeling experience, the Mining Data Analysis System (MDAS) was used to represent the source-response linkage in the Guyandotte watershed for aluminum, iron, manganese, and fecal coliform bacteria. The MDAS is a comprehensive data management and modeling system that is capable of representing loading from the nonpoint and point sources found in the Guyandotte watershed and simulating in-stream processes. Metals are modeled within MDAS in total recoverable form. Therefore, it is necessary to link MDAS with the Dynamic Equilibrium In-stream Chemical Reactions model (DESC) to appropriately address dissolved aluminum TMDLs in the Guyandotte watershed. The MINTEQ modeling system is used to represent the source-response linkage in the Guyandotte watershed for pH. The methodologies and technical approaches for dissolved aluminum and pH are discussed in sections 4.4 and 4.5, respectively.

4.2 Mining Data Analysis System (MDAS) Overview

The MDAS is a system designed to support TMDL development for areas impacted by AMD. The system integrates the following:

- Graphical interface
- Data storage and management system

- Dynamic watershed model
- Data analysis/post-processing system

The graphical interface supports basic geographic information system (GIS) functions, including electronic geographic data importation and manipulation. Key data sets include stream networks, landuse, flow and water quality monitoring station locations, weather station locations, and permitted facility locations. The data storage and management system functions as a database and supports storage of all data pertinent to TMDL development, including water quality observations, flow observations, permitted facility Discharge Monitoring Reports (DMR), as well as stream and watershed characteristics used for modeling. The system also includes functions for inventorying the data sets. The Dynamic Watershed Model, also referred to as the Hydrological Simulation Program - C++ (HSPC), simulates nonpoint source flow and pollutant loading as well as in-stream flow and pollutant transport, and is capable of representing time-variable point source contributions. The data analysis/post-processing system conducts correlation and statistical analyses and enables the user to plot model results and observation data.

The most critical component of the MDAS to TMDL development is the HSPC model, because it provides the linkage between source contributions and in-stream response. The HSPC is a comprehensive watershed model used to simulate watershed hydrology and pollutant transport as well as stream hydraulics and in-stream water quality. It is capable of simulating flow, sediment, metals, nutrients, pesticides, and other conventional pollutants, as well as temperature and pH for pervious and impervious lands and waterbodies. The HSPC is essentially a re-coded C++ version of selected Hydrologic Simulation Program-FORTRAN (HSPF) modules. HSPC's algorithms are identical to those in HSPF. Table 4-1 presents the modules from HSPF used in HSPC. Refer to the *Hydrologic Simulation Program FORTRAN User's Manual for Release 11* for a more detailed discussion of simulated processes and model parameters (Bicknell et al., 1996).

Table 4-1. Modules from HSPF[a] converted to HSPC

RCHRES Modules	HYDR	Simulates hydraulic behavior
	CONS	Simulates conservative constituents
	HTRCH	Simulates heat exchange and water
	SEDTRN	Simulates behavior of inorganic sediment
	GQUAL	Simulates behavior of a generalized quality constituent
	PHCARB	Simulates pH, carbon dioxide, total inorganic carbon, and alkalinity
PQUAL and IQUAL Modules	PWATER	Simulates water budget for a pervious land segment
	SEDMNT	Simulates production and removal of sediment
	PWTGAS	Estimates water temperature and dissolved gas concentrations
	IQUAL	Uses simple relationships with solids and water yield
	PQUAL	Simple relationships with sediment and water yield

[a] Source: Bicknell et al., 1996

4.3 MDAS Model Configuration

The MDAS was configured for the Guyandotte watershed, and the HSPC model was used to simulate the watershed as a series of hydrologically connected subwatersheds. Configuration of the model involved subdivision of the Guyandotte watershed into modeling units and continuous simulation of flow and water quality for these units using meteorological, landuse, point source loading, and stream data. Specific pollutants that were simulated include total aluminum, total iron, total manganese, and fecal coliforms. This section describes the configuration process and key components of the model in greater detail.

4.3.1 Watershed Subdivision

To represent watershed loadings and resulting concentrations of metals in the Guyandotte River watershed, the watershed was divided into 369 subwatersheds. These subwatersheds are presented in Figure 1 in each of Appendices A-1 through A-14, and they represent hydrologic boundaries. The division was based on elevation data (7.5 minute Digital Elevation Model [DEM] from USGS), stream connectivity (from USGS's National Hydrography Dataset [NHD] stream coverage), impairment status of tributaries, and locations of monitoring stations.

4.3.2 Meteorological Data

Meteorological data are a critical component of the watershed model. Appropriate representation of precipitation, wind speed, potential evapotranspiration, cloud cover, temperature, and dewpoint are required to develop a valid model. Meteorological data were accessed from a number of sources in an effort to develop the most representative dataset for the Guyandotte watershed.

In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in development of a representative dataset. Long-term hourly precipitation data available from five National Climatic Data Center (NCDC) weather stations located near the watershed were used (Figure 4-1):

- Huntington/Tri-State Airport
- Griffithsville
- Flat Top
- Dry Creek
- Logan

Meteorological data for the remaining required parameters were available from the Beckley-Raleigh County Airport and Charleston WSO Airport stations. These data were applied based on subwatershed location relative to the weather stations.

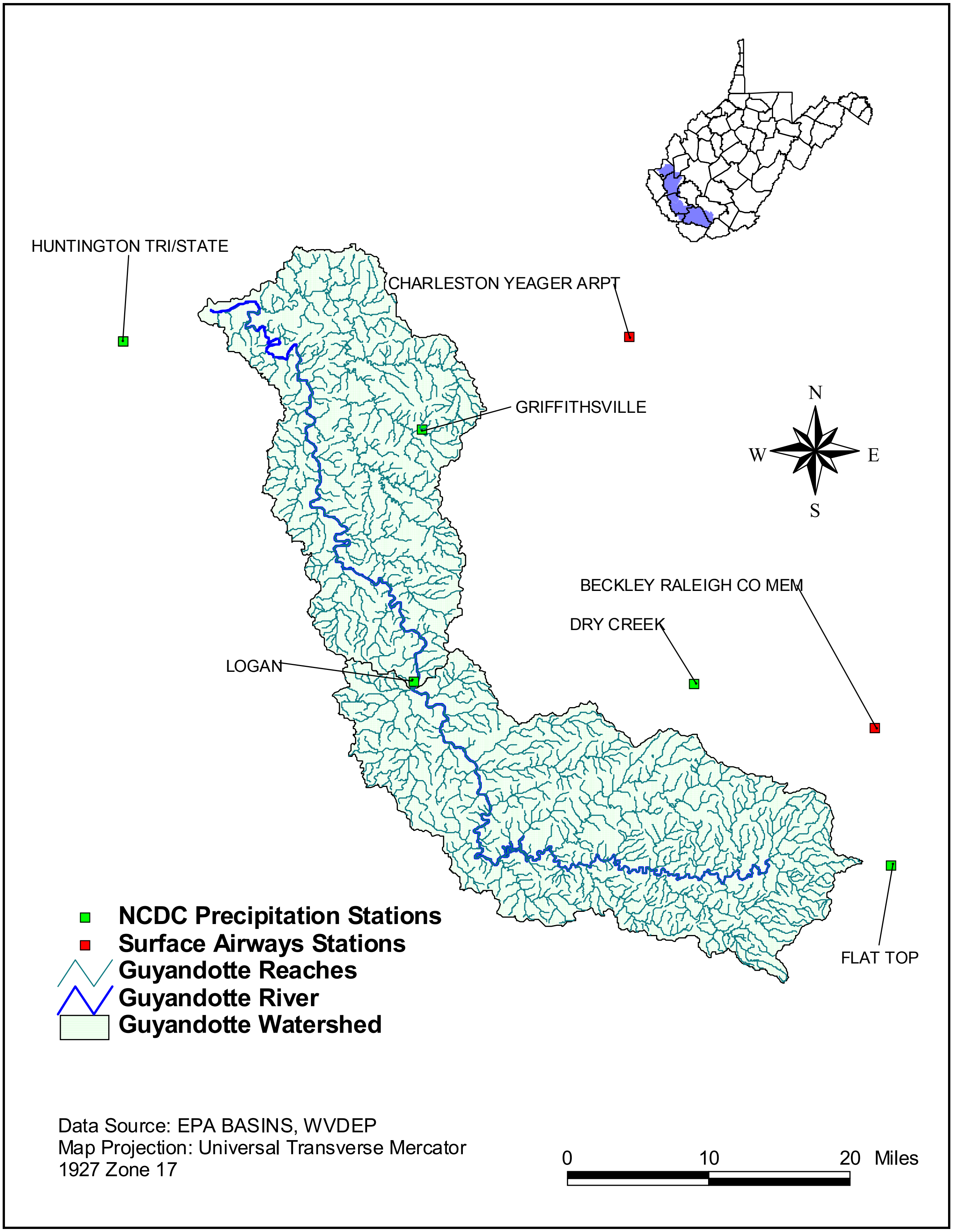


Figure 4-1. Weather stations used in modeling of the Guyandotte Watershed

The use of meteorological data over a period from 1980 to 2002 further ensures that the TMDL methodology is consistent with the technical and regulatory requirements of 40 CFR Section 130. These regulations require TMDLs to consider critical environmental conditions and seasonal environmental variations. The requirements are designed to simultaneously ensure that water quality is protected during times when it is most vulnerable and take into account changes in streamflow and loading characteristics as a result of hydrological or climatological variations. These conditions are important because they describe the factors that combine to cause violations of water quality standards and can help identify necessary remedial actions. The selected period of meteorological data includes extreme wet and dry periods that allow consideration of critical conditions.

4.3.3 Representation of Metals Sources Without NPDES Permits

To explicitly model nonpoint and/or unpermitted sources in the Guyandotte River watershed, the existing GAP 2000 landuse categories were consolidated to create model landuse groupings, shown in Table 4-2. Several additional landuse categories were created and added to the model landuse groupings. The additional landuse categories are explained in the following sections. The updated landuse coverage provided the basis for estimating and distributing total aluminum, iron, and manganese loadings associated with conventional landuses.

Contributions of relevant parameters from groundwater sources are also considered. In the case of naturally-occurring parameters, such as aluminum, iron, and manganese, it is important to consider and incorporate groundwater contributions for a more accurate representation of actual conditions.

Table 4-2. Metals model landuse grouping

Model Category	
Barren	Barren land - mining / construction
Cropland	Row Crop Agriculture
Mature Forest	Shrubland
	Conifer Plantation
	Floodplain Forest
	Cove Hardwood Forest
	Diverse / Mesophytic hardwood Forest
	Hardwood / Conifer Forest
	Oak dominant forest
	Mountain Hardwood Forest
	Mountain Hardwood / Conifer Forest
	Mountain Conifer Forest
	Woodland
	Major Powerline
	Pasture/Grassland
Pasture	Planted Grassland
Urban Impervious (See Table 4-3)	Major Highways (90% impervious)
	Populated Area - mixed land Cove (15% impervious)r
	Light intensity urban (15% impervious)
	Moderate intensity urban (50% impervious)
	Intensive Urban (80% impervious)

Model Category	GAP2000 Category
Urban Pervious (See Table 4-3)	Major Highways (10% pervious)
	Populated Area - mixed land Cover (85% pervious)
	Light intensity urban (85% pervious)
	Moderate intensity urban (50% pervious)
	Intensive Urban (20% pervious)
Water	Surface Water 1
	Surface Water 2
Wetlands	Forested Wetland
	Shrub Wetland
	Herbaceous Wetland

Abandoned Mine Lands (AML)

The AML categories were broken down into three landuse categories: high walls, disturbed land, and abandoned mines. The abandoned mines represent either discharge from abandoned deep mines or seeps and leachate from other abandoned mine sites. Specific data regarding the three AML landuses was not available from the GAP 2000 landuse coverage. WVDEP provided AML landuse coverage data which were incorporated into the GAP 2000 landuse coverage. In order to incorporate these landuses to appropriately account for runoff and loading characteristics, the existing GAP 2000 landuse coverage was modified on a subwatershed basis. For instance, assume that data from WVDEP indicated no active mining, 60 acres of abandoned mines, 40 acres of disturbed land, and 20 acres of high walls in a particular subwatershed, while available GAP 2000 data indicated 900 acres of forested land and 100 acres of “active mining land” in the same watershed. The GAP 2000 data would be modified such that the 100 acres of “active mining land” would become 120 acres of AML landuse distributed according to the WVDEP data (i.e. 60 acres of abandoned mines, 40 acres of disturbed land, and 20 acres of high walls). Because the size of the new AML landuse coverage exceeds the original “active mining land” coverage by 20 acres, the forested landuse coverage is reduced by 20 acres such that the total size of the watershed remains constant. In no case was the total size of any subwatershed modified as a result of including more accurate data regarding AML landuses.

Sediment Sources

Additional landuse categories were required to represent differences in the sediment loading and transport characteristics from various landuse activities. Separate landuse categories were designated for forest harvest areas (recent timber removal), burned forest (areas disturbed by forest fires) oil and gas operations, paved roads, and unpaved roads.

The West Virginia Bureau of Commerce, Division of Forestry provided information on the registered logging in the Guyandotte watershed. This information included the area of land that is logged and a sub-set of land that has been disturbed by roads and landings over the past five years. The Division of Forestry also provided information on the forested areas that have been disturbed by forest fires over the past five years. Both the harvested and burned areas can be found in Appendix E. Harvested areas and burned areas then were subtracted from the Mature Forest landuse category. The harvested forest and burned forest landuse categories represent the total timber harvested and burned in each subwatershed.

WVDEP Office of Oil and Gas (WVDEP OOG) provided information regarding oil and gas operations in the Guyandotte River watershed. Active oil and gas operations were assumed to have a well site and access road area of approximately 6,400 square feet. This assumption was supported by results from a random well survey conducted by WVDEP OOG in the Elk River watershed during the summer of 2001 that showed similar average well site and access road areas. The cumulative area for oil and gas operations in each subwatershed was subtracted from the mature forest categories as stated above.

Information on paved and unpaved roads in the watershed was obtained from the Census 2000 TIGER/Line Files. These GIS files provide the location and length of roads for the entire country. Each road is also assigned a code based on its attributes. The codes start with an A, and are followed by a number. The codes are described below in Table 4-3. The lengths of roads by subwatershed were calculated by intersecting the Tiger Road shapefile with the subwatershed delineation. Following this, an estimated width was assigned to each category of roads, to obtain an area. Based on the description for the appropriate category, the roads were designated as paved, unpaved, or in the case of A4, 60% paved, and 40% unpaved. Unpaved road areas were subtracted from mature forest lands. Paved road areas were subtracted from the urban impervious landuse category and then from forest lands if necessary.

Table 4-3. Assigned perviousness and estimated width for each type of road

Code	Description	Percent Pervious	Estimated Width (ft)
A1	Primary Highway With Limited Access	0%	35
A2	Primary Road Without Limited Access	0%	35
A3	Secondary and Connecting Road	0%	26
A4	Local, Neighborhood, and Rural Road	40%	16
A5	Vehicular Trail	100%	12
A6	Road with Special Characteristics	0%	12
A7	Road as Other Thoroughfare	0%	12

From: Census 2000 TIGER/Line® Technical Documentation

Feature Class A, Roads Description:

A1 - Primary Highway With Limited Access

Interstate highways and some toll highways are in this category (A1) and are distinguished by the presence of interchanges. These highways are accessed by way of ramps and have multiple lanes of traffic. The opposing traffic lanes are divided by a median strip.

A2 - Primary Road Without Limited Access

This category (A2) includes nationally and regionally important highways that do not have limited access as required by category A1. It consists mainly of US highways, but may include some state highways and county highways that connect cities and larger towns. A road in this category must be hard-surface (concrete or asphalt). It has intersections with other roads, may be divided or undivided, and have multi-lane or single-lane characteristics.

A3 - Secondary and Connecting Road

This category (A3) includes mostly state highways, but may include some county highways that connect smaller towns, subdivisions, and neighborhoods. The roads in this category generally are smaller than roads in Category A2, must be hard-surface (concrete or asphalt), and are usually undivided with single-lane characteristics. These roads usually have a local name along with a route number and intersect with many other roads and driveways.

A4 - Local, Neighborhood, and Rural Road

A road in this category (A4) is used for local traffic and usually has a single lane of traffic in each direction. In an urban area, this is a neighborhood road and street that is not a thorough-fare belonging in categories A2 or A3. In a rural area, this is a short-distance road connecting the smallest towns; the road may or may not have a state or county route number. Scenic park roads, unimproved or unpaved roads, and industrial roads are included in this category. Most roads in the Nation are classified as A4 roads.

A5 - Vehicular Trail

A road in this category (A5) is usable only by four-wheel drive vehicles, is usually a one-lane dirt trail, and is found almost exclusively in very rural areas. Sometimes the road is called a fire road or logging road and may include an abandoned railroad grade where the tracks have been removed. Minor, unpaved roads usable by ordinary cars and trucks belong in category A4, not A5.

A6 - Road with Special Characteristics

This category (A6) includes roads, portions of a road, intersections of a road, or the ends of a road that are parts of the vehicular highway system and have separately identifiable characteristics.

A7 - Road as Other Thoroughfare

A road in this category (A7) is not part of the vehicular highway system. It is used by bicyclists or pedestrians, and is typically inaccessible to mainstream motor traffic except for private-owner and service vehicles. This category includes foot and hiking trails located on park and forest land, as well as stairs or walkways that follow a road right-of-way and have names similar to road names.

Other Sources

Impervious urban lands contribute nonpoint source metals loads to the receiving streams through the washoff of metals that build up in industrial areas, on paved roads, and in other urban areas because of human activities. Percent impervious estimates for urban landuse categories were used to calculate the total area of impervious urban land in each subwatershed. Pervious and impervious urban land areas were estimated using typical percent pervious/impervious assumptions for urban land categories, as shown in Table 4-4.

Table 4-4. Average percent perviousness and imperviousness for different landuse types

Landuse	Pervious (%)	Impervious (%)
Pasture	100	0
Cropland	100	0
Forest	100	0
Barren	100	0
Wetlands	100	0
Populated Areas	85	15
Light Intensity Urban	85	15
Moderate Intensity Urban	50	50
Intensive Urban	20	80
Major Highway	10	90

4.3.4 Fecal Coliform Bacteria Nonpoint and/or Unpermitted Source Representation

To explicitly model nonpoint and/or unpermitted sources of fecal coliform bacteria in the Guyandotte River watershed, the existing GAP 2000 landuse categories were consolidated to create model landuse groupings, shown in Table 4-5. The updated landuse coverage provided the basis for estimating and distributing fecal coliform bacteria loadings associated with conventional landuses.

In addition, contributions of fecal coliform bacteria from groundwater sources are also considered. In the case of naturally-occurring parameters, such as fecal coliform bacteria, it is important to consider and incorporate groundwater contributions for a more accurate representation of actual conditions.

Table 4-5. Fecal coliform bacteria model landuse grouping

Model Category	
Barren	Barren Land - Mining / Construction
Cropland	Row Crop Agriculture
Forest	Mountain Hardwood Forest
	Conifer Plantation
	Floodplain Forest
	Cove Hardwood Forest
	Diverse / Mesophytic Hardwood Forest
	Shrubland
	Oak Dominant Forest
	Woodland
	Mountain Hardwood / Conifer Forest
	Mountain Conifer Forest
	Major Powerline
	Hardwood / Conifer Forest
Pasture	Pasture / Grassland
	Planted Grassland
Urban Impervious (See Table 4-4)	Intensive Urban (80% impervious)
	Major Highway (90% impervious)
	Populated Area - Mixed Land Cover (15% impervious)

Model Category	GAP2000 Category
	Light Intensity Urban (15% impervious)
	Moderate Intensity Urban (50% impervious)
Urban Pervious (See Table 4-4)	Major Highway (10% pervious)
	Intensive Urban (20% pervious)
	Light Intensity Urban (85% pervious)
	Moderate Intensity Urban (50% pervious)
	Populated Area - Mixed Land Cover (85% pervious)
Water	Surface Water 1
	Surface Water 2
Wetlands	Forested Wetland
	Shrub Wetland
	Herbaceous Wetland

The nonpoint and/or unpermitted fecal coliform sources within the Guyandotte River watershed are represented differently in the model depending on their type and behavior. The following nonpoint and/or unpermitted fecal coliform sources have been identified within the listed watersheds:

- Urban and residential runoff
- Leaking sanitary sewers
- Failing septic systems and straight pipe discharges
- Grazing livestock
- Runoff from cropland
- Wildlife

Frequently, nonpoint sources are characterized by build-up and wash-off processes. Bacteria accumulates on land surfaces where it is subject to die-off and wash-off with surface water runoff. These nonpoint sources are represented in the model as land-based runoff from the landuse categories. Fecal coliform accumulation rates (number per acre per day) can be calculated for each landuse based on all sources contributing fecal coliforms to the land surface. For example, grazing livestock and wildlife are specific sources contributing to landuses within the watershed. The landuses that experience bacteria accumulation due to livestock and wildlife include:

- Cropland (wildlife)
- Forest (wildlife)
- Pasture (livestock and wildlife)
- Wetlands (wildlife)

Accumulation rates can be derived using the distribution of animals by landuse and using typical fecal coliform production rates for different animal types (Table 4-6). For example, the fecal coliform bacteria's accumulation rate for pasture lands is the sum of the individual fecal coliform accumulation rates due to contributions from grazing livestock (cattle) and wildlife.

Table 4-6. Fecal coliform production rates for beef cattle and deer

Animal	Fecal Coliform Production Rate	Reference
Beef cow	1.0×10^{11} counts/day	ASAE, 1998
Deer	5×10^{8} counts/day	Linear interpolation; Metcalf & Eddy, 1991

Direct contributions to the waterbodies from in-stream cattle were not included in this TMDL modeling effort because of the relatively small number of cattle estimated to be in the watershed (see Section 3.5.6).

Urban lands contribute nonpoint source fecal coliform bacteria loads to the receiving streams through the washoff of fecal coliform bacteria that build up on both pervious and impervious surfaces in industrial areas, on paved roads, and in residential areas because of human activities and wildlife. Percent pervious and impervious estimates for urban landuse categories were used to calculate the total area of urban pervious and urban impervious land in each subwatershed. Pervious and impervious urban land areas were estimated using typical percent pervious/impervious assumptions for various types of urban landuses, as shown in Table 4-4.

Literature values for typical fecal coliform bacteria accumulation rates were used to calculate the fecal coliform bacteria accumulation rates for urban areas. Urban areas were consolidated into two landuse categories: urban pervious and urban impervious, based on typical percent pervious/imperviousness for the various urban landuse types (Table 4-5). The calculated fecal accumulation rate used for urban impervious is 9.33 E+06 fecal coliform counts/ac/day, and the value used for urban pervious is 7.53 E+09 fecal coliform counts/ac/day. The fecal coliform contribution from family pets (dogs) was included in the urban pervious accumulation rate by assuming one pet per household, using the number of households in each county as listed in the 1990 census data. The literature value used for the fecal coliform production rate for domestic animals is 4.09E+09 #/animal/day (LIRPB, 1978). The contribution from domestic pets was included in the total fecal accumulation rate for pervious urban areas, assuming dogs remained mostly on the pervious surfaces associated with low-density residential areas.

Failing septic systems and straight pipes represent sources that can contribute fecal coliforms to receiving waterbodies through surface or subsurface flow. The number of septic systems and straight pipes per subwatershed were determined using U.S. Census data. The 1990 Census provided the number of unsewered homes for census tracts in Boone, Cabell, Lincoln, Logan, Mingo, Putnam, Raleigh, and Wyoming counties. The number was then divided by the total census tract area to obtain a density of unsewered homes. The density was then applied to the corresponding subwatershed on an area-weighted basis. Figures 4-2 and 4-3 show the estimated number of unsewered homes in the Guyandotte River watershed.

The number of homes served by septic systems and straight pipes was estimated from the number of unsewered homes in the Guyandotte River watershed. Areas within the Guyandotte

River watershed where discharges of untreated sewage are known to occur were identified by WVDEP Construction Assistance staff. For the subwatersheds lying in these areas, it was assumed that 25% of the unsewered homes in the subwatershed were discharging untreated sewage directly to the waterbody (straight pipes) and 75% of the unsewered homes were served by septic systems. For other unsewered areas, it was assumed that 10% of the unsewered homes were discharging untreated sewage directly to the waterbody and 90% of the unsewered homes were served by septic systems. For the areas within the Guyandotte watershed that are known to be served by sewer systems, it was assumed that 100% of the unsewered homes were served by septic systems. A failure rate of 70% was applied to the number of homes served by septic systems in each subwatershed to determine the number of failing septic systems to be represented in the model. To provide for a margin of safety accounting for the uncertainty of the number, location, and behavior (e.g., surface vs. subsurface breakouts; proximity to stream) of the straight pipes and failing systems, they are represented in the model as direct sources of fecal coliforms to the stream reaches. Fecal coliform contributions from failing septic system and straight pipe discharges are included in the model with a representative flow and concentration, which were quantified based on the following information:

- Number of straight pipes in each subwatershed.
- Number of failing septic systems in each subwatershed (failure rate of 70% discussed in Section 3.5.6).
- Estimated population served by the septic systems and straight pipes (calculated from census tract averages of people per household, obtained from 1990 Bureau of the Census data).
- An average daily discharge of 70 gallons/person/day (Horsley & Witten, 1996).
- Straight pipe effluent concentration of 1.0 E+06 fecal coliform counts/100 mL (septic effluent concentration from Horsley & Witten, 1996).
- Septic effluent concentration reaching the stream of 1.0 E+04 fecal coliform counts/100 mL (estimated using the septic effluent concentration from Horsley & Witten, 1996, accounting for die-off between septic tank and stream).

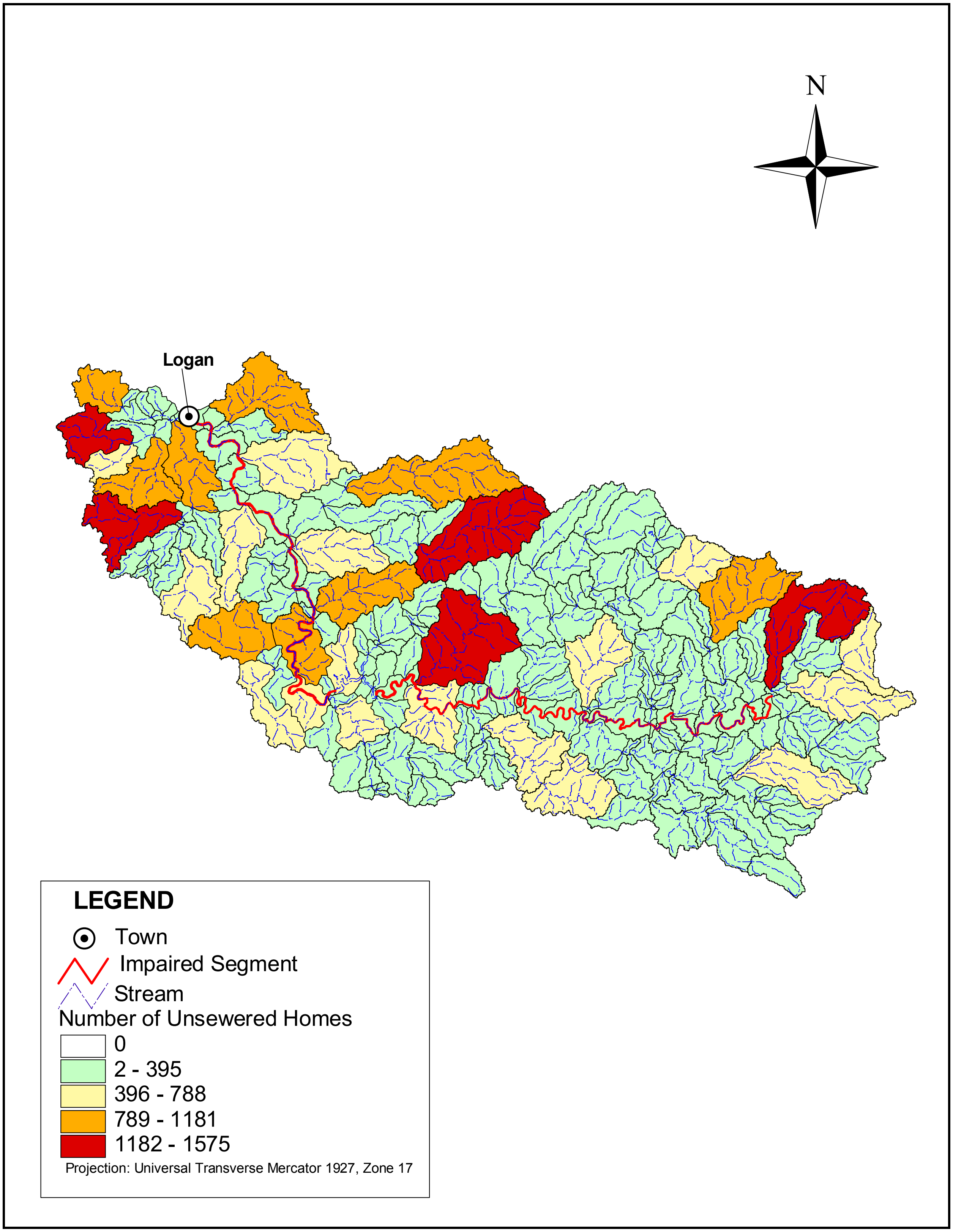


Figure 4-2. Number of unsewered homes in the Upper Guyandotte River watershed

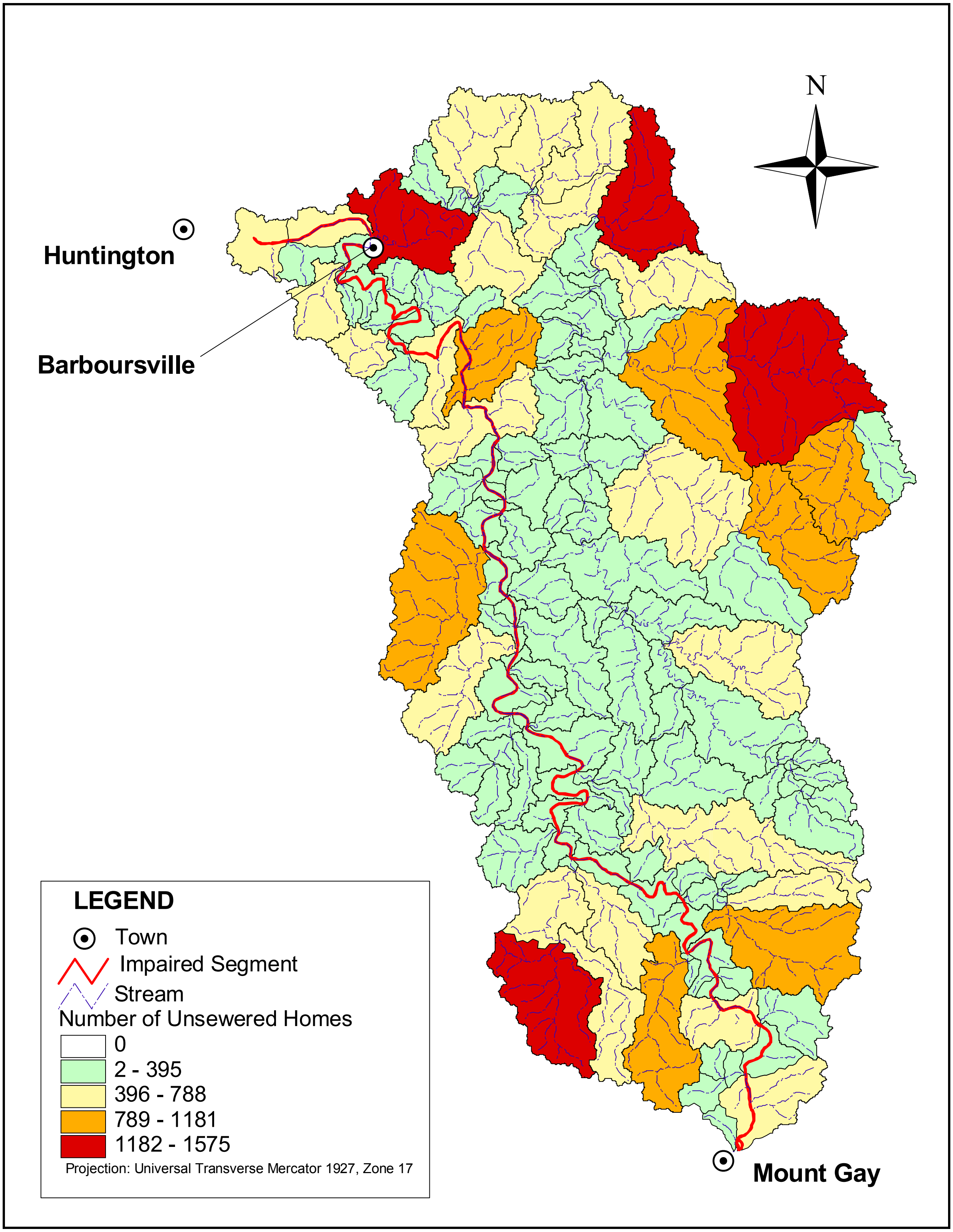


Figure 4-3. Number of unsewered homes in the Lower Guyandotte River watershed

4.3.5 Permitted Metals Source Representation

Permitted Non-mining Point Sources

As stated in Section 3, there are three non-mining point sources in the Guyandotte watershed that are permitted to discharge metals. These point sources were represented in MDAS as continuous flow point sources using the design flow of each facility and the permit limits listed in Table 3-3. Under this TMDL, these minor discharges are assumed to operate under their current permit limits. These facilities will be assigned WLAs that allow them to discharge at their current permit limits.

Permitted Mining Point Sources

The permitted mining point sources were introduced as nine landuse categories based on the type of mine and the current status of the mine. Phase II and Completely Released permitted facilities were not modeled since reclamation of these mines is either completed or nearly complete, and they are assumed to have little potential water quality impact (WVDEP, 2000a). Table 4-7 shows the landuses representing current active mines that were modeled.

Table 4-7. Model nonpoint source representation of different permitted mines

Type and status of active mine	Landuse representation
Active deep mines	ADM
Active surface mines, renewed surface mines	ASM
Inactive deep mines, new deep mines	IADM
Inactive surface mines, new surface mines	IASM
Other mines (other, haulroad, prospect, quarry)	Other
Phase 1 released deep mines	PIDM
Phase 1 released surface mines	PISM
Revoked deep mines	RDM
Revoked surface mines	RSM
Revoked other mines	ROM

To account for the additional deep mine landuse categories that were not categorized in the GAP 2000 landuse coverage (ADM, IADM, RDM and PIDM), the area of each permitted deep mine was subtracted from the existing GAP 2000 landuse area as described in Section 4.3.3. The remaining additional landuse categories (ASM, PISM, RSM, ROM and Other) were subtracted from the barren landuse areas. Due to the lack of information available, the size of each mine was assumed to be equivalent to the surface disturbed area, which was provided by WVDEP DMR mining permit database. To account for this assumption, the hydrologic parameters within the model were adjusted to make the permitted mine landuses simulate continuous flow discharges. These areas are shown in Appendix B. A summary of the landuse distribution is shown in Table 4-8a and Table 4-8b.

Table 4-8a. Modeled landuse distribution in acres for Regions 1 through 7

Modeled Landuse	1	2	3	4	5	6	7
ADM	0	0	0	0	0	84	879
Agriculture	421	771	2	2	0	0	4
AML	622	72	0	3	116	5,009	1,486
ASM	14	3,909	0	0	4	3,733	8,598
Barren	656	961	0	39	100	113	64
Burned Forest	2,074	2,051	884	1,521	228	2,211	7,302
Forest	136,274	176,154	22,212	25,991	17,594	48,991	158,180
Harvested Forest	515	1,472	184	23	0	679	1,865
Highwall	171	21	0	2	26	496	976
IADM	4	17	0	2	0	146	305
IASM	0	36	0	0	51	1,299	1,269
Oil and Gas	108	164	31	23	9	15	88
OM	47	0	0	0	6	803	2,010
P1DM	0	0	0	0	0	72	150
P1SM	0	0	0	0	0	666	1,079
Pasture	16,180	30,213	397	1,327	473	682	3,619
Paved Roads	1,243	1,322	75	128	106	305	1,000
RDM	90	0	0	0	0	50	102
ROM	0	0	0	0	0	92	120
RSM	0	0	0	0	0	487	1,353
Skid Roads	39	111	14	2	0	51	140
Unpaved Roads	619	710	59	79	51	155	487
Urban Impervious	2,220	2,555	0	0	0	65	184
Urban Pervious	7,251	7,151	0	2	9	1,117	1,983
Water	3,556	2,030	4	9	3	56	3,365
Wetland	81	334	0	0	1	2	24
Total	**172,185**	**230,054**	**23,862**	**29,153**	**18,777**	**67,379**	**196,632**

Table 4-8b. Modeled landuse distribution in acres for Regions 8 through 14

Modeled Landuse	8	9	10	11	12	13	
Barren	54	76	0	35	89	149	391
Mature Forest	3	0	0	47	0	0	0
Cropland	175	21	17	1,917	19	583	968
InterForest	2,345	823	10	1,838	670	523	0
Pasture	0	0	7	6	0	58	51
Strip Mining	248	2,907	437	798	359	176	785
Urban Imper	22,128	27,608	25,160	69,638	23,816	30,968	84,783
Urban Per	334	110	65	1,318	275	801	5,805
Wetlands	133	120	96	536	9	55	474
Water	10	11	5	116	0	84	108
Annual Forest Harvest	279	726	0	147	1,093	1,542	446
Paved Roads	14	21	14	50	25	11	38
Unpaved Roads	722	0	0	1,178	75	206	421
Oil & Gas Ops	0	11	26	33	13	13	44
ADM	1,545	408	0	264	0	0	0
IADM	151	165	137	2,409	670	820	4,619
RDM	162	151	105	346	82	116	513
PIDM	0	7	9	0	0	0	127
ASM	0	0	0	0	0	0	9
RSM	196	0	0	10	0	0	8

Modeled Landuse	8	9	10	11	12	13	14
PIRS	25	8	5	99	21	60	437
OTHER	115	64	47	177	52	85	291
ROM	4	0	1	46	7	201	187
AML	443	158	94	780	45	154	1,236
Disturbed	7	2	1	599	9	39	132
Highwall	0	1	2	58	1	12	45
Total	**29,093**	**33,398**	**26,238**	**82,445**	**27,330**	**36,656**	**101,918**

Point sources were represented differently, depending on the modeling scenario for TMDL development. The two major scenarios, which are described in more detail later in this section and in Section 5, are the model calibration scenario and the allocation scenarios.

Calibration Condition

To match model results to historical data, which is described in more detail in the Model Calibration section (4.6), it was necessary to represent the existing point sources using available historical data. The period selected for water quality calibration, 1994-2001, was the time period for which monitoring data were available. Discharges that were issued permits after the calibration period were not considered during the calibration process. If time-series Discharge Monitoring Report data (DMRs) were available, continuous flow permitted mines were represented in the model using average flows and pollutant loads. The DMR data includes monthly average and maximum daily values for flow, pH, total aluminum, total iron, and manganese. The monthly average metals concentrations were multiplied by the discharge flows to estimate average loadings for these point sources.

In most cases, time-series DMRs were insufficient to support representation in the model, indicating that the permitted mine discharges were precipitation driven. For these situations, discharges from permitted mines were represented in the model by adjusting parameters affecting pollutant concentrations in the PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules of HSPC. These parameters were assigned using 75th percentile DMR concentrations of similar mining activities within the entire Guyandotte watershed. Concentrations from these mines were adjusted to be consistent with typical discharge characteristics from similar mining activities or to match site-specific in-stream monitoring data.

Allocation Conditions

Modeling for allocation conditions required running multiple scenarios, including a baseline scenario and multiple allocation scenarios. This process is further explained in Section 5. For the allocation conditions, all permitted mining facilities were represented using precipitation-driven nonpoint source processes in the model. The period of 1987 to 1992, which represents a range of precipitation conditions, was applied to the sources that are present today for the allocation scenario. Under this nonpoint source representation, flow was estimated in a manner similar to other nonpoint sources in the watershed (i.e., based on precipitation and hydrologic properties). This is consistent with WV DMR’s estimation that discharges from most surface mines are precipitation-driven (WVDEP, 2000b). Discharges from deep mines are typically continuous flow and were estimated by the method described earlier in this section. Under baseline conditions, the concentration of metals from point source discharges, including NPDES mining permits, was consistent with permit limits; i.e., the waste load allocation (WLA) based on permit limits. During the allocation scenario, reductions were applied to abandoned mine lands, sediment producing lands, and active mines in order to achieve in-stream TMDL endpoints.

Mining discharge permits have either technology-based or water quality-based limits. Monthly average permit concentrations for technology-based limits are 3.0 mg/L and 2.0 mg/L for total iron and manganese, respectively, with a “report only” limit for total aluminum. Monitoring requirements for dissolved aluminum are currently being addressed by permit reissuance (see section 1.4). Permitted discharges with water quality-based limits must meet in-stream water quality criteria at end-of-pipe. Point sources were assigned concentrations based on the appropriate limits. For technology-based permits, the waste load concentration for aluminum was assumed to be the 98th percentile value of the available DMR data for mining discharges in the Guyandotte River watershed (3.72 mg/L).

Allocations were made to provide consistency with the technical and regulatory requirements of 40 CFR Section 130. For instance, following the data analysis and model calibration, it was determined that violations of applicable water quality criteria occur at both low-flow and high-flow conditions. Accordingly, the TMDL, model calibration, and allocation process were designed to consider both low-flow and high-flow conditions.

4.3.6 Fecal Coliform Permitted Source Representation

A total of 382 point sources have NPDES permits regulating fecal coliform bacteria discharge to the Guyandotte River and its tributaries (see Section 3.4). 138 of the permits for fecal coliforms are general sewage permits. These general sewage point sources are represented in MDAS with a constant flow and fecal coliform count. The representative constant flow is the design flow provided in the NPDES permit for each facility. The fecal coliform discharges from each of the facilities are represented in the MDAS model by the monthly average discharge limitation of 200 fecal coliform counts/100 mL provided in the NPDES permits.

222 of the point sources with NPDES permits regulating the discharge of fecal coliform bacteria are the HAUs discussed in Section 3.4.3. HAUs were represented in the model by their design flow and the average monthly permitted fecal coliform discharge of 200 counts /100mL.

The 22 remaining point sources are regulated by individual NPDES permits that contain fecal coliform effluent limits. 17 of these are designated as Publicly Owned Treatment Works (POTW). Sewage treatment facilities operating under individual permits were represented in the model by their design flow and the average monthly permitted fecal coliform limit of 200 counts/100 ml.

4.3.7 Stream Representation

Modeling subwatersheds and calibrating hydrologic and water quality model components requires routing flow and pollutants through streams and comparing the modeled concentrations to water quality criteria. Each subwatershed was represented with a single stream. Stream segments were identified using the USGS NHD stream coverage.

To route flow and pollutants, rating curves must be developed. Rating curves were developed for each stream using Manning's equation and representative stream data. Required stream data include slope, Manning's roughness coefficient, and stream dimensions, including mean depths and channel widths. Manning's roughness coefficient was assumed to be 0.05 for all streams (representative of natural streams). Slopes were calculated based on digital elevation model (DEM) data and stream lengths measured from the NHD stream coverage. Stream dimensions were estimated using regression curves that relate upstream drainage area to stream dimensions (Rosgen, 1996).

4.3.8 Hydrologic Representation

Hydrologic processes were represented in the HSPC using algorithms from the PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules of HSPF (Bicknell et al., 1996). Parameters associated with infiltration, groundwater flow, and overland flow were designated during model calibration.

4.3.9 Pollutant Representation

In addition to flow, four pollutants were modeled with the HSPC:

- Total aluminum
- Total iron
- Total manganese
- Fecal coliform bacteria

The loading contributions of these pollutants from different nonpoint sources were represented in the HSPC using the PQUAL (simulation of quality constituents for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules in HSPF (Bicknell et al., 1996). Pollutant transport was represented in the streams using the GQUAL (simulation of behavior of a generalized quality constituent) module. Values for the pollutant representation were refined through the water quality calibration process.

4.4 Dissolved Aluminum TMDL Methodology using Dynamic Equilibrium in-Stream Chemical reactions (DESC)

As stated previously, it was necessary to link the watershed model (MDAS) with the Dynamic Equilibrium in-Stream Chemical reactions model (DESC) to appropriately address dissolved aluminum TMDLs in the Guyandotte River watershed. To establish this linkage, the MDAS model was first set up and calibrated to simulate in-stream concentrations of total metals (iron, aluminum, and manganese). The MDAS calibration process is discussed in detail in Section 4.6. Once calibration was complete, the time series flow and water quality output from MDAS was entered in the DESC to simulate dissolved metals behavior. DESC was then calibrated to further refine the simulation of dissolved metals. The current version of the model supports daily MDAS output files as time series input (the model will interpolate input values based on smaller time steps for the model to be stable).

4.4.1 DESC Overview

The (DESC) model dynamically simulates fate and transport of chemical pollutants in surface water. DESC is capable of simulating water quality in a multiple watershed setting by routing flow from upstream to downstream while simulating the transformation of in-stream water quality constituents.

The DESC model is composed of two major components:

- simulation of pollutant transport and
- simulation of selected chemical reactions using MINTEQ computational codes (EPA, 1991).

The model includes advective and diffusive transport equations that are solved using a numerical solution of the explicit finite difference method. The chemical equilibrium solutions are solved using the Newton-Raphson approximation method to solve mass balance (linear) and mass action equations (nonlinear) as in MINTEQ. The model can simulate various chemical reactions as long as thermodynamic data is available to the model. The MINTEQ database contains information for more than 5,000 chemical reactions. If a targeted chemical reaction is not available in the database, it can be added by the user. For the pollutant transport routine, the DESC utilizes time series or constant total chemical concentrations and flow and the physical characteristics of the stream as inputs. The transport routine assumes one-dimensional trapezoidal stream cross-sections with in-stream concentrations equally distributed throughout each segment. Time series average depth data from the watershed model is used to estimate time series flow. The model fully connects all chemical reactions with the transport routine and pollutants are routed from upstream to downstream allowing for loading inputs from landuses. The model supports all major chemical reactions and some kinetic reactions that need to be considered in the mining-affected stream. Examples of these reactions include:

- Adsorption of metals onto iron oxide included on the surface of clay or other soil particles
- Adsorption of metals onto aluminum oxide
- Saturation calculations with dissolved and precipitated conditions within the water column and sediment
- Kinetic photo iron reduction
- Microbial iron oxidation
- Homogeneous oxidation processes

4.4.2 DESC Calibration

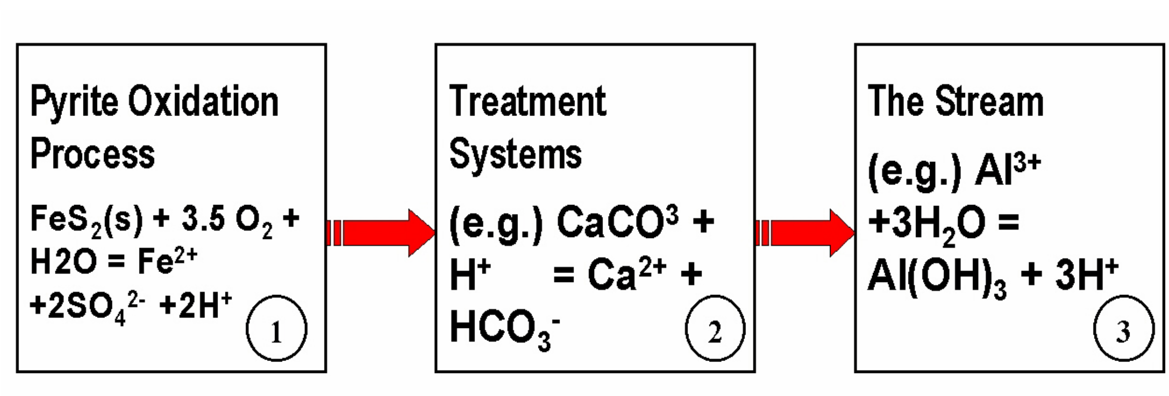
The DESC is equipped with an option for either manual or automatic calibration. The main parameters used to calibrate total and dissolved concentrations are alkalinity values in streams, the settling velocity of freshly precipitated materials, and the time required for precipitated material to be inactive. Theses values were derived based on observed data or literature values. Examples of some of the calibration parameters are listed below:

- Settling velocity
- Incoming ratio of ferric and ferrous iron into the first stream segment
- Selection of solubility constants depending on the maturity of precipitated materials
- Light energy
- Carbonate concentration
- Particle surface area percentage
- Time required for precipitated material to be inactive

4.5 pH TMDL Methodology Overview

4.5.1 Overview

Streams affected by acid mine drainage often exhibit high metals concentrations (specifically for iron [Fe], aluminum [Al], and manganese [Mn]) along with low pH. The relationship between these metals and pH provides justification for using metals TMDLs as a surrogate for a separate pH TMDL calculation. The following figure shows three representative physical components that are critical to establishing this relationship.



Note: Several major ions compose the water chemistry of a stream. The cations are usually Ca^{2+}, Mg^{2+}, Na^+, K^+, and H^+, and the anions consist of HCO_3^-, CO_3^{2-}, NO_3^-, Cl^-, SO_4^{2-}, and OH^- (Stumm and Morgan, 1996).

Component 1 describes the beginning oxidation process of pyrite (FeS_2) resulting from its exposure to H_2O and O_2. This process is common in mining areas. The kinetics of pyrite oxidation processes are also affected by bacteria (Thiobacillus ferrooxidans), pH, pyrite surface area, crystallinity, and temperature (PADEP, 2000). The overall stoichiometric reaction of the pyrite oxidation process is as follows:

$$FeS_2(s) + 3.75\ O_2 + 3.5\ H_2O \longrightarrow Fe(OH)_3\ (s) + 2SO_4^{2-} + 4H^+$$

Component 2 presents an example chemical reaction occurring within a mining treatment system. Examples of treatment systems include wetlands, successive alkalinity-producing systems, and open limestone channels. Carbonate and other bases (e.g., hydroxide) created in treatment systems consume hydrogen ions produced by pyrite oxidation and hydrolysis of metals, thereby increasing pH. The increased pH of the solution will precipitate metals as metal hydroxides. Treatment systems may not necessarily work properly, however, because the removal rate of metals, and therefore the attenuation of pH, depends on chemical constituents of the inflow; the age of the systems; and physical characteristics of the systems such as flow rate and detention rate (West Virginia University Extension Service, 2000).

It is assumed that implementing TMDLs in the Guyandotte watershed for dissolved aluminum, total iron, and total manganese will result in in-stream metals concentrations that meet the water quality criteria. This assumes that treatment systems are implemented properly and effectively increase pH in order to precipitate metals and thus lower their in-stream concentrations.

After treatment, the focus shifts to Component 3 and the relationship between metals concentrations and pH in the stream. The chemical process that needs to be considered is the hydrolysis reaction of metals in the stream. Component 3 presents an example of this reaction. To estimate the pH resulting from chemical reactions occurring in the stream, MINTEQA2, a geochemical equilibrium speciation model for dilute aqueous systems, was used.

4.5.2 MINTEQA2 Application

MINTEQA2 is an EPA geochemical equilibrium speciation model capable of computing equilibrium aqueous speciation, adsorption, gas phase partitioning, solid phase saturation states, and precipitation-dissolution of metals in an environmental or lab setting. The model includes an extensive database of reliable thermodynamic data. The MINTEQA2 model was run for each of the pH impaired streams in the Guyandotte watershed using the inputs shown in Table 4-9.

Table 4-9. Input values for MINTEQA2

Species	Input Values (mg/L)
Ca	18
Mg	12
Na [(a)]	6.3
K [(a)]	2.3
Cl [(a)]	7.8
SO_4	77.0
Fe [(b)]	1.5
Al	Maximum observed value for specific pH impaired stream
Mn [(b)]	1.0
Alkalinity	56.0 (as $CaCO_3$)

[a] source: Livingstone (1963)
[b] allowable maximum concentrations (TMDL endpoints)

Input values for Fe and Mn were based on TMDL endpoints (maximum allowable limits). Since dissolved aluminum TMDLs were only developed for selected streams in the Guyandotte watershed, aluminum TMDL endpoints could not be used. Therefore, the maximum observed concentrations for the specific pH impaired stream were used as the total aluminum inputs. The alkalinity value was based on the geometric mean of observed in-stream concentrations in the Guyandotte watershed. Similarly, the geometric mean of observation values were used for the remaining ions requiring input for MINTEQA2. Where observation data were not available, literature values were used for the chemical species. Additionally, the model was set to equilibrium with atmospheric CO_2. The resultant equilibrium pH for each of the pH impaired streams are presented in Table 4-10.

Table 4-10. MINTEQA2 results for the pH impaired streams in the Guyandotte River watershed

DNR Name	DNR Code	Pollutant	Maximum Observed Total Aluminum (ug/L)	pH (MINTEQ)
Buffalo Creek	OG-61	pH	9.96	7.40
Buffalo Creek/Little Huff Creek	OG-92-K	pH	0.20	8.28
Coal Branch/Island Creek	OG-65-A	pH	3.00	8.14
Copperas Mine Fork	OG-65-B	pH	3.90	8.09
Ed Stone Branch/Big Creek	OG-49-A	pH	0.87	8.25
Ellis Branch/Mud Fork	OG-65-B-1-B	pH	0.29	8.27
Godby Branch	OG-53	pH	4.65	8.03
Limestone Branch	OG-48	pH	0.90	8.25
Lower Dempsey Branch	OG-65-B-1-A	pH	3.70	8.10
Measle Fork	OG-134-D	pH	5.79	7.94
Mud Fork	OG-65-B-1	pH	1.80	8.21
North Branch/Big Creek Ed Stone Branch	OG-49-A-1	pH	1.52	8.22
Oldhouse Branch/Rockhouse Creek	OG-77-A.5	pH	8.00	7.65
Proctor Hollow/Buffalo Creek	OG-75-C.5	pH	3.00	8.14
Right Fork/Buffalo Creek	OG-61-A	pH	no value	-
Trace Fork/Copperas Mine Fork	OG-65-B-4	pH	3.00	8.14
Upper Dempsey Branch	OG-65-B-1-E	pH	6.70	7.84

Results from MINTEQA2 imply that pH will be within the West Virginia criterion of above six and below nine (inclusive), provided that in-stream metals concentrations simultaneously meet applicable water quality criteria. Once in-stream metal concentrations are within water quality criteria, natural alkalinity present within the Guyandotte River watershed will also help to resolve pH impairments.

4.5.3 Assumptions

The chemical processes generating AMD and the processes to treat AMD are subject to many variables which may or may not be addressed in the chemical equations. Some of these variables are discussed below.

Iron (Fe)

Ferric iron was selected as total iron based on the assumption that the stream will be in equilibrium with the atmospheric oxygen. Because iron exhibits oxidized and reduced states, the redox portion of the iron reactions may need to be considered. The reduced state of iron, ferrous iron, can be oxidized to ferric iron through abiotic and biotic oxidation processes in the stream. The first process refers to oxidation by increasing the dissolved oxygen through the mixing of flow. The other process is oxidation by microbial activity in acidic conditions on bedrock (Mcknight and Bencala, 1990). Photoreduction of hydrous oxides can also increase the dissolved ferrous form. This reaction could increase the pH of the stream followed by oxidation and hydrolysis reactions of ferrous iron (Mcknight, Kimball and Bencala, 1988). Since water quality data are limited, the concentration of total Fe was assumed to be constant at 1.5 mg/L, and it was assumed that the total Fe increase by photoreduction would be negligent. This assumption could ignore pH changes during daytime.

Sodium (Na), Potassium (K), and Chloride (Cl)

The concentration of Na, K, and Cl can be higher in streams affected by acid mine drainage. These ions are conservative and are not reactive in natural water, however, so it is likely that the pH of the stream would not be affected.

Calcium (Ca), Magnesium (Mg)

Ca and Mg ions may have higher concentrations than the values used for the modeling in this study due to the dissolution of minerals under acidic conditions and the reactions within treatment systems. Increasing the concentrations of these ions in the stream, however, could result in more complex forms with sulfate in the treatment system and in the river. This should not affect pH.

Manganese (Mn)

Manganese oxide (MnO_2) can have a redox reaction with ferrous iron and produce ferric iron (Evangelou, 1998). This ferric iron can then undergo a hydrolysis reaction and produce hydrogen ions, thereby decreasing pH.

Biological Activities

Biological activities such as photosynthesis, respiration, and aerobic decay can influence the pH of localized areas in the stream. Biological reactions such as the following:

$$CO_2 + H_2O \longleftrightarrow 1/6\ C_6H_{12}O_6 + O_2$$

will assimilate CO_2 during photosynthesis and produce CO_2 during respiration or aerobic decay. Reducing CO_2 levels will increase the pH and increasing CO_2 levels will lower the pH of the water (Langmuir, 1997). It is possible that as a result of these biological activities, the pH standards might be violated even though metals concentrations are below in-stream water quality standards.

Kinetic Considerations

The kinetic aspect of metal reactions in the stream is an important factor that also needs to be considered. For example, Fe and Mn can be oxidized very rapidly if the pH of the solution is 7.5 to 8.5; otherwise, the oxidization process is much slower (Evangelou, 1995). Violation of metals concentrations without pH violation might be a result of reaction kinetics.

4.6 MDAS Model Calibration

After the model was configured, calibration was performed at multiple locations throughout the Guyandotte River watershed. Calibration refers to the adjustment or fine-tuning of modeling parameters to reproduce observations. Model calibration focused on two main areas: hydrology and water quality. Upon completion of the calibration at selected locations, the calibrated dataset containing parameter values for modeled sources and pollutants was complete. This dataset was applied to areas where calibration data were not available.

A significant amount of time-varying monitoring data were necessary to calibrate the model. Available monitoring data in the watershed were identified and assessed for application to calibration (Tables 3a, 3b, 3c. 3d, 3e, 3f, 3g, 3h and 3i in each of Appendices A-1 through A-14). Only monitoring stations with data that represented a range of hydrologic conditions, source types, and pollutants were selected.

4.6.1 Hydrology Calibration

Hydrology was the first model component calibrated. The hydrology calibration involved a comparison of model results to in-stream flow observations at selected locations and the subsequent adjustment of hydrologic parameters. Key considerations included the overall water balance, the high-flow low-flow distribution, storm flows, and seasonal variation.

In order to best represent hydrologic variability throughout the watershed, three locations with daily flow monitoring data were selected for calibration. The stations were USGS 03204000 Guyandotte at Branchland, USGS 03203600 Guyandotte at Logan, and USGS 03202750 Clear Fork at Clear Fork. The model was calibrated at these three locations for water years 1994 and 1995 by running the model over a calibration time period of 10/1/1993 - 9/30/1995. Flow-frequency curves, temporal comparisons (daily and monthly), and comparisons of high flows and low flows were developed to support calibration. The calibration involved adjustment of infiltration, subsurface storage, evapotranspiration, surface runoff, and interception storage parameters.

After adjusting the appropriate parameters within acceptable ranges, good correlations were found between model results and observed data for the comparisons made. Flow-frequency curves and temporal analyses are presented in Appendix F. Hydrology calibration statistics are shown in Table 4-11.

Parameter values were validated for an independent, extended time period (10/1/1983 through 9/30/1993) after calibrating parameters at the stations. The station chosen for validation was USGS 0320400 Guyandotte at Branchland. Validation involved comparison of model results and flow observations without further adjustment of parameters. The validation comparisons also showed a good correlation between modeled and observed data. Figure 4-4 presents a monthly summary of validation results. Refer to Appendix F for more detailed validation results.

Table 4-11. Comparison of simulated and observed flow for water years 1994 and 1995 (USGS 03203600)

Simulated versus Observed Flow	Percent Error	Recommended Criterion[1]
Error in total volume	**12.49**	+/- 10%
Error in 50% lowest flows	**32.94**	+/- 10%
Error in 10% highest flows	**-3.43**	+/- 15%
Seasonal volume error - Summer	**26.14**	+/- 30%
Seasonal volume error - Fall	**28.77**	+/- 30%
Seasonal volume error - Winter	**1.20**	+/- 30%
Seasonal volume error - Spring	**18.62**	+/- 30%
Error in storm volumes	**-17.58**	+/- 20%
Error in summer storm volumes	**-14.48**	+/- 50%

[1] Recommended Criterion: HSPExp

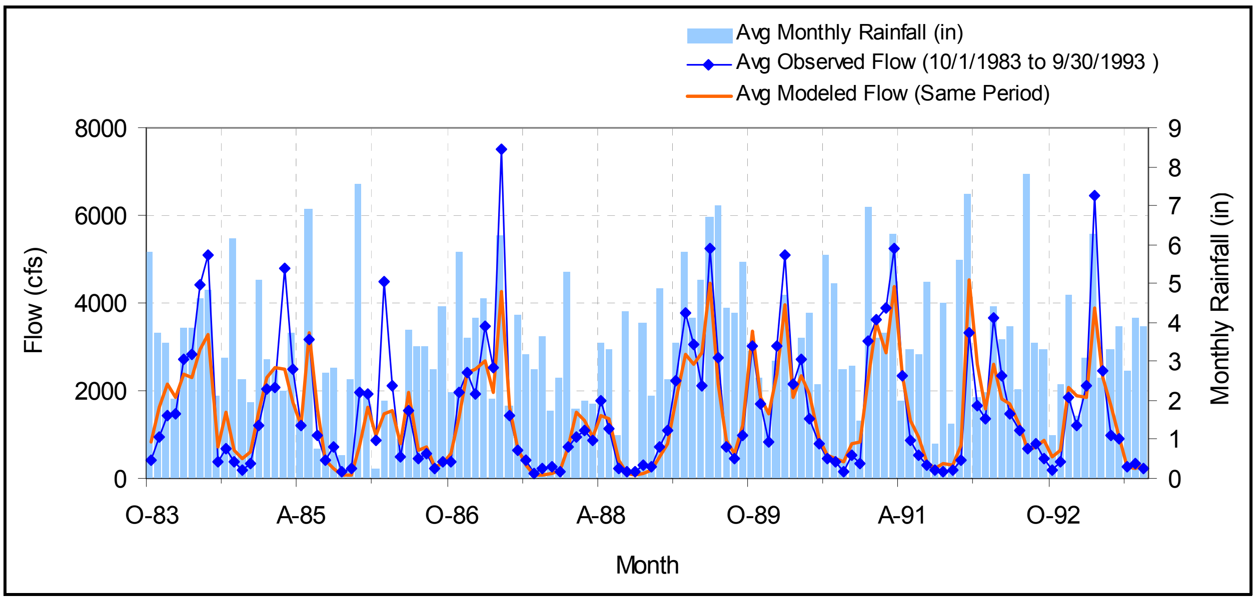


Figure 4-4. Comparison of Simulated and Observed Flow for the validation period (USGS 0320400 Guyandotte at Branchland)

4.6.2 Water Quality Calibration

After calibration for hydrology is complete, water quality calibration is performed. In the broadest sense, calibration consists of executing the watershed model, comparing time series water quality output to available water quality observation data, and adjusting water quality parameters within a reasonable range. In order to establish reasonable ranges for use in water quality calibration, DMR and high flow data were analyzed to develop appropriate water quality parameters for active mines (surface, deep, and other mines, but not AML or revoked mines) and barren lands. Reasonable water quality parameters for AML were based on previous watershed modeling experience in areas with AML (*pH and Metals TMDLs for the Tug Fork River Watershed, 2002* and *pH and Metals TMDL for the West Fork River Watershed, 2002*). Parameters for background conditions were based on observed water quality data.

The approach taken to calibrate water quality focused on matching trends identified during the water quality analysis. The water quality calibration period was 1994-2001. Daily average in-stream concentrations from the model were compared directly to observed data. Observed data were obtained from EPA’s STORET database as well as from WVDEP Division of Water and Waste Management, and data submitted by various mining companies throughout the watershed. All data were obtained through WVDEP. The objective was to best simulate low flow, mean flow, and storm peaks at representative water quality monitoring stations. Representative stations were selected based on both location (distributed throughout the Guyandotte watershed) and loading source type. Results of the water quality calibration are presented in Appendix F.

4.7. Selenium TMDL Methodology Overview

As discussed in Section 4-1, the TMDL approach must consider the dominant processes regarding pollutant loadings and in-stream fate. For the impaired tributaries of the upper Mud River, the primary sources contributing to selenium impairments are the point sources associated with the surface mines. A pollutant flow analysis was performed in order to evaluate critical flow periods for comparison to water quality criteria for selenium. Measured flow data and the observed in-stream concentrations from Stations 6 through 9 were used in the analyses. In general, in-stream selenium concentrations increased during low flow conditions as shown in Figure 4-5.

The critical low flow condition was determined by calculating the 7Q10 flow for the streams in the upper Mud River watershed. Since there are no USGS flow gaging stations in the upper Mud River watershed that have data for extended periods, the calibrated model flow from MDAS was used to determine the low flow 7Q10 conditions. Based on the 7Q10 analyses, all areas upstream of Upton Branch have a low flow 7Q10 of 0cfs as shown in Figure 4-6.

Since the primary sources contributing to selenium impairments are the point sources at a low flow 7Q10 condition of 0 cfs, the nonpoint source contributions of selenium were considered to be negligible. Therefore, the TMDLs were based on wasteload allocations assigned at water quality criteria for selenium at the end of pipe for the surface mining discharging upstream of the 7Q10 condition of 0cfs (Upton Branch).

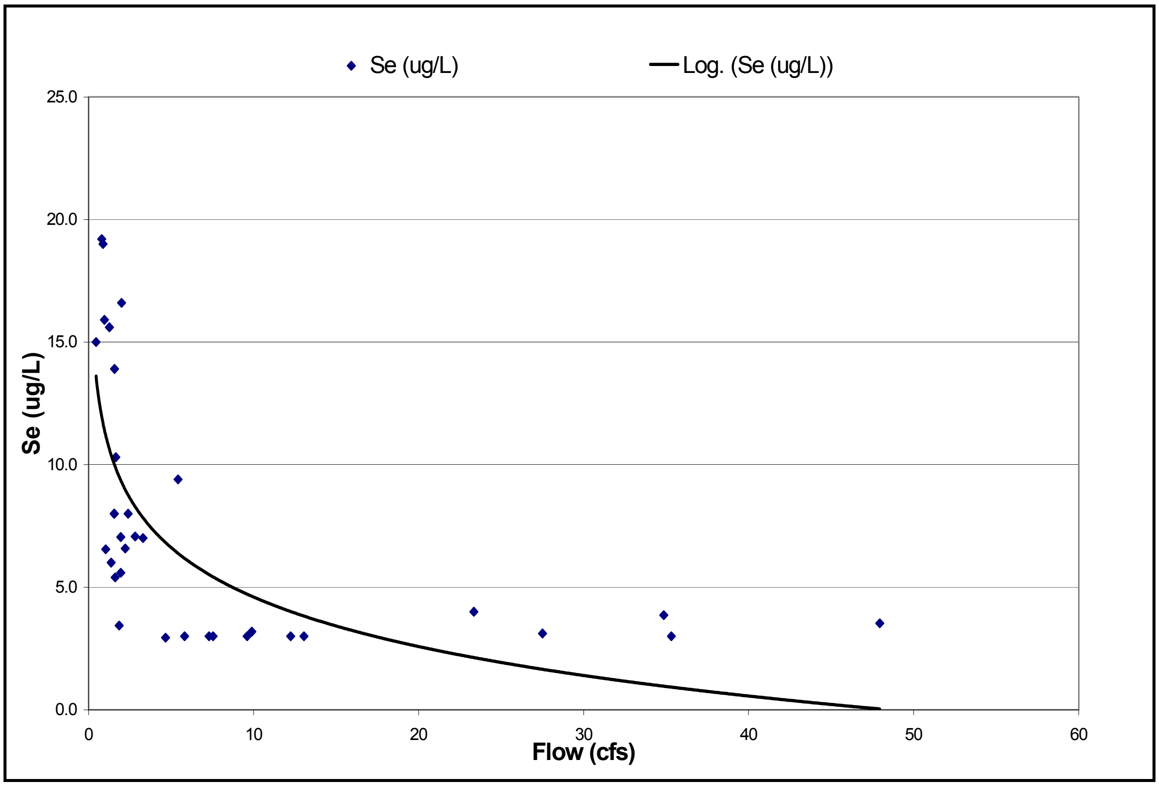


Figure 4-5. Selenium-Flow correlation analysis for Stations 6 through 9

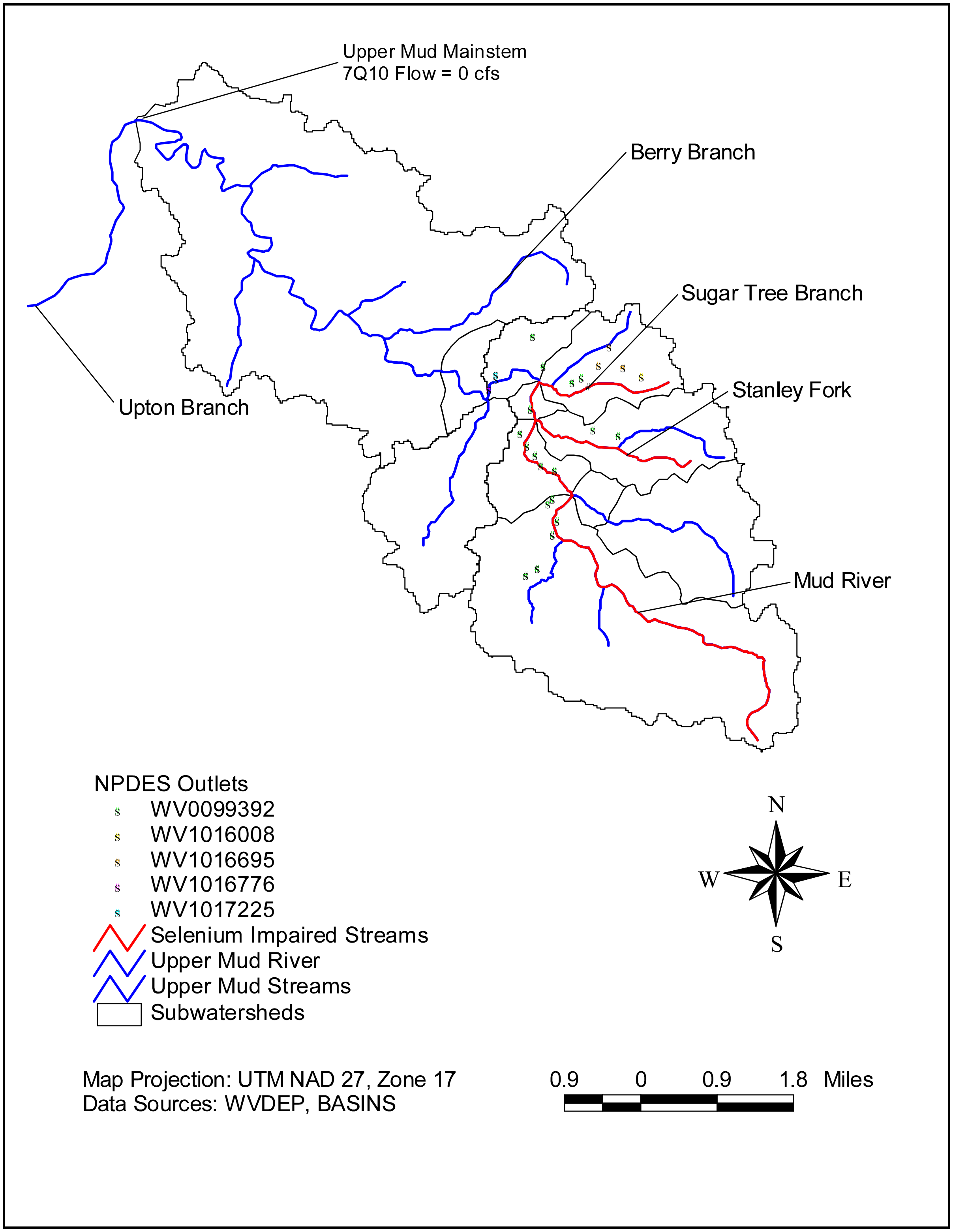


Figure 4-6. Upper Mud Watershed where the low 7Q10 flow was calculated to be 0 cfs